Structural quality of soil in plantation: a case study on the mixed plantation of *Alnus cremastogyne* and *Cupressus funebris* in upper reaches of Yangtze River

LIAO Chao-lin[1, 2], HE Yu-rong[1*], ZHANG Bao-hua[3]

[1] *Institute of Mountain Hazards and Environments, CAS, Chengdu 610041, P. R. China*

[2] *Graduate School of Chinese Academic of Sciences, Beijing 100039, P. R. China*

[3] *Liaocheng university, Liaocheng Shangdong 252059, P. R. China*

Abstract: In process of ecological construction in typical region of upper reaches of Yangtze River, China, the mixed plantations at the ages of 10-20 present a trend to be pure forests and degeneration. Soil samples including stratified soil and total soil were taken from 4 typical profiles in the mixed plantation of *Alnus cremastogyne* and *Cupressus funebris* in Yanting County in central Sichuan, China. Soil indices of the plantation were compared with those of natural forest in Gongga Mountain in the same region. The results revealed that structural quality of soil in plantation was significantly lower than that in natural forests. The degradation of structural quality of soil in plantation was one of key factors for plantation degeneration. The degradation causes of structural quality of soil were analyzed. Aanthropogenic disturbance and absence of effective protection and scientific management are the main reason for degradation of structural quality of soil in plantation. The main countermeasures, e.g. forest reservation, ecological rehabilitation, litter horizon rebuilding as well as organic fertilizer application, were proposed to improve the structural quality of soil in plantation.

Keywords: Plantation; Soil structural quality; Countermeasure; Yangtze River

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Introduction

Soil quality has attracted much attention from researchers throughout the world since the 1990s and it is also defined with new implication (Doran and Parkin 1994; Pankhurst *et al*. 1995; Zhao *et al*. 1997). Many indices have bee used to study and assess the soil fertility (Cao 2004), and the structural quality of soil is one of the essential indices. To date a series of achievements have been attained in soil quality research. However, most of those studies focused on the cultivated land, and little research work of soil quality were carried out on woodland, especially plantation land. Nowadays the protection of natural forests and the program of conversion from cropland to forest or grassland (so-called "double protection programs" (DPP)) in the upper reaches of Yangtze River of China have been implementing. It is of significance to draw some lessons from the plantation construction and provide some useful information for successfully implementing DPP.

In 1970s, the ecological forest was constructed in some regions of upper reaches of Yangtze River to improve the ecological environment. For example, the construction of the mixed plantation of *Alnus cremastogyne* and *Cupressus funebris* in hilly region of central Sichuan improved the agro-ecological environment substantially in 10 years after afforestation. However, almost 20 years later, many *A. cremastogyne* trees died and the *C. funebris* grew very slowly; as a result, the forest declined and lost the function of improving ecological system. This case is probably related to soil degradation in plantation. Besides the ecological features of forest, the degradation of structural quality of soil under forest is one of important influencing factors.

In this study, the typical soil in plantation in hilly region of central Sichuan in upper reaches of Yangtze River was selected as a case study, and comparison was made with the undisturbed soil under natural forest of Gongga Mountain in the same region. The problems in structural quality of soil and countermeasures of plantation degradation were probed for providing data for making the countermeasures on DPP to promote sustainable environmental benefit.

Materials and methods

The soil sampling was conducted in the mixed plantation of *Alnus cremastogyne* and *Cupressus funebris* in Linshan Town, Yanting County in central Sichuan and the natural forest in the east slope of Gongga Mountain were selected as the control. The site conditions were reported in the papers of Zhang *et al.* (2003) and He *et al.* (2004, 2005). Soil type, soil formation conditions and growing status of trees in woodland are listed in Table 1.

Soil samples including stratified soil and total soil were taken from 4 typical profiles in the fall of 2003. In each sampling profile, three soil samples were collected in different soil horizons and were mixed as the analyzing samples. The soil samples were air-dried, passed through a 2-mm mesh, and homogenized. Soil aggregates, soil particle size distribution, soil porosity and soil water retention capacity were determined respectively by dry-wet sieving method, pipette method and flat method (Nanjing Institute of Soil Science, the Chinese Academy of Soil Science 1978). Soil pH was measured by using acidity-meter, SOM was determined by the sulfuric acid-potassium dichromate method and CEC was analyzed by NH_4Ac leaching method (Nanjing Institute of Soil Science, the Chinese Academy of Soil Science 1978).

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Biography: LIAO Chao-lin (1975-), male, Ph.D. candidate, Institute of Mountain Hazards and Environments, Chinese Academy of Sciences, Chengdu, 610041, P. R. China. Email: clliao@163.com

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*Corresponding author: HE yu-rong (Email: yrh@imde.ac.cn).

Results

Constitution and structural features of soil profiles

The constitution features of typical soil profiles and soil basic properties of plantation in hilly region of central Sichuan, as well as those of natural forests in Gongga Mountain, are shown in Table 2. The results revealed that, comparing with the soil profiles under natural forest, the typical soil profiles in plantations were absent of litter layers (A_0), and their soils were high alkaline, low content of organic matter and high content of sand fraction.

Table 1. Site conditions of woodland in sampling region

Site	Soil type/profile number	Site conditions	Trees species
Plantation	Purplic-Orthic Primosols YT-07	Located in Wenniuwan, Linshan, Yanting County, with an altitude of 460 m, parent materials of Penglaizhen Group (J_{3p}) sandstone and mudstone, top slope	mixed plantation of *Alnus cremastogyne* and *Cupressus funebris* constructed in 1972, having been pure *Cupressus funebris*，bad growth of *Alnus cremastogyne*
	Purplic Udic-Orthic Cambosols YT-08	Located in Wenniuwan, Linshan, Yanting County, with an altitude of 455m, parent materials of Penglaizhen Group (J_{3p}) sandstone and mudstone, top slope	mixed plantation of *Alnus cremastogyne* and *Cupressus funebris* constructed in 1972, a little residual *Alnus cremastogyne*, bad growth of woods, thining
	Purplic Udic-Orthic Cambosols YT-09	Located in Duangouwan, Linshan, Yanting County，with an altitude of 450 m, parent materials of Penglaizhen Group (J_{3p}) sandstone and mudstone, upper slope	mixed plantation of *Alnus cremastogyne* and *Cupressus funebris* constructed in 1972, a little *Alder*, thin growth of trees
Natural forest	Umbric-Gelic Cambosols GG-01	Located on the East Slope of Mt. Gongga, with an altitude of 3200m, parent materials of slope deposits mainly composed of sericite-quartz sandstone weathering products, middle steep slope	Exuberant growing natural Matured *Fir* forest

Notes: Soil type was identified based on Chinese Soil Taxonomy (third edition).

Table 2. Features of soil profile and soil basic properties

Profile No	Soil horizon	Depth (cm)	SOM %	pH (1:5)	CEC (cmol/g)	Soil particle size distribution %		
						2-0.05mm	0.05-0.002mm	<0.002mm
YT-07	A_1	2–20	2.6	8.80	27.59	36.23	47.83	15.94
	AC	20–70	1.5	8.81	21.32	38.35	45.11	16.54
	C	70-	0.4	8.94	26.10	41.10	40.67	18.23
YT-08	A_1	2–10	2.4	7.96	26.31	35.75	48.40	15.85
	B_W	10–30	1.6	8.05	13.95	39.44	44.41	16.15
	C	30–100	0.4	7.90	11.62	28.05	52.27	19.68
YT-09	A_1	2–12	2.5	8.81	26.29	27.30	53.57	19.13
	B_W	12–30	1.4	8.38	27.13	28.32	48.74	22.94
	C	30–70	0.5	8.90	24.16	23.81	54.54	21.65
GG-01	A_0	0–5	–	–	–	–	–	–
	A_1	5–15	29.2	4.17	70.52	80.02	17.60	5.28
	B_W	15–28	25.4	5.07	61.43	81.93	12.65	5.42
	C	28–43	10.7	5.27	41.65	84.23	13.41	2.36

Distribution of soil aggregates

The compositions of soil aggregates and microaggregates in typical woodland were listed in Table 3.

Composition of common soil aggregate

(1) The content of soil aggregates (>0.25mm in diameter) ranged from 91.60% to 96.39% for dry sieving in plantations and 24.02% to 73.43% for wet sieving. Although the soil aggregate content (>0.25mm) under natural forest determined by dry sieving was low, the content of water stable aggregate (>0.25mm in diameter) determined by wet sieving ranged from 79.95% to 85.15%; (2) The soil aggregate contents in different particle sizes (>0.25mm in diameter) had a great variation for the soil in plantation, ranged from 1% to 49%, but a smaller variation for natural forest; (3) The gaps between the amounts of dry and wet sieving of different range aggregates for the soil in plantation were much bigger than those of natural forest, ranged from –7.1% to 43.5%. According to both amount and distribution of aggregate and soil water stability mentioned above, and the soil structural status in plantation was far inferior to those under natural forest. He *et al.* (2004, 2005) reported the micromorphological features of soil microstructural quality in plantation and natural forest, and their results agree with the results mentioned above.

Composition of soil microaggregate

It is well known that the content of microaggregate with 0.25—2 mm and 0.05—0.25 mm in diameter has a significant effect on the soil fertility. From Table 3, the contents of soil mi-

croaggregate in plantation ranged from 9% to 25% for microaggregate of 0.25—2 mm in diameter and 10% to 31% for microaggregate of 0.05—0.25mm, while, correspondingly, that of soil in natural forest ranged from 42% to 53% and 44% to 45%. Evidently, the content of microaggregate in plantation was significantly lower than those under natural forest.

Soil porosity and distribution

The soil porosity under different forests was shown in Table 4. The total porosity in natural forest ranged from 62% to 72% and non-capillary porosity varied between 21% and 28%, whereas The total porosity and non-capillary porosity of soil in plantation were 42%—51% and 33%—39%, respectively. Both soil aeration and water holding capacity in plantation were lower than those in natural forest. The soil equivalent pore (30—100μm in diameter) in natural forest and plantation, which reflected water retention ability, ranged from 17% to 27% and 8% to 11%, respectively, the latter was far lower than the former.

Table 3. Composition of soil aggregate

Profile No/soil horizon	Aggregate (dry sieving/wet sieving) %			Microaggregate %			
	>2 mm	2–0.25 mm	<0.25 mm	0.25—2 mm	0.25—0.05 mm	0.05—0.01 mm	<0.01 mm
YT07-A	86.99/15.27	7.94/19.07	5.07/65.66	13.67	25.19	26.10	35.04
YT07-AC	76.00/5.85	15.56/18.17	8.40/75.98	8.77	30.50	13.16	47.57
YT08-A	85.65/56.87	9.65/16.56	4.70/26.57	25.32	15.44	29.04	30.20
YT08-AC	80.99/50.73	14.41/19.51	4.60/41.22	21.74	19.96	19.43	38.87
YT09-A	81.07/37.35	15.32/24.64	3.61/38.01	22.81	10.23	27.62	39.34
YT09-AC	73.19/26.12	20.77/15.81	6.11/58.07	17.27	14.86	24.83	43.04
GG01-A	58.07/55.32	32.15/29.83	9.78/14.85	50.60	43.96	1.32	4.12
GG01-B_W	53.31/43.60	32.71/36.35	13.98/20.05	42.42	45.03	3.86	8.69

Table 4. Soil bulk density and porosity (volume proportion)

Profile No of soil	Soil bulk density ($Mg\cdot m^{-3}$)	Total porosity %	Capillary pore %	Non-capillary porosity %	Equivalent pore %		
					30–100 μm	3–30 μm	<3% μm
YT07A	1.637	42.0	32.5	9.5	8.7	5.6	27.7
-AC	1.492	43.2	34.4	8.8	8.1	6.0	29.1
YT08A	1.357	44.7	33.8	10.9	10.9	7.5	26.3
-B_W	1.349	46.3	35.8	10.5	10.7	6.9	28.7
YT09A	1.385	44.4	34.2	10.2	8.8	7.9	27.7
-B_W	1.371	51.1	38.9	12.2	12.1	5.8	33.2
GG01-A	0.589	70.6	44.2	24.4	20.8	19.4	30.4
GG0-B_W	0.622	68.2	45.1	23.1	20.0	19.3	28.9

Assessment of structural quality of soil in woodland

Structural quality of soil is generally assessed according to structural elements such as composition, morphology and amount of soil aggregate and porosity besides soil structural stability. Correctly choosing assessing index and method is a key for evaluating the structural quality of soil. In this study, the following six assessing indices of soil structure were chosen based on the studies of Zhu (1996) and Barthes and Roose (2002):

(1) Mean weight-diameter of aggregate (M_{WD})

$$M_{WD}=\sum\omega_i\chi_i, \tag{1}$$

where ω_i is the mean diameter of each particle size fraction and χ_i is the proportion of total sample weight in the corresponding particle size fraction, including the one that passes through the finest sieve.

(2) Structural coefficient (S_C)

$$S_C = 1 - \frac{M_{A<0.001}}{P_{<0.001}} \times 100\,\% \tag{2}$$

where, $M_{A<0.001}$ and $P_{<0.001}$ represent accumulative contents of soil microaggregates and particle in diameter smaller than 0.001 mm, respectively.

(3) Aggregation status (A_S)

A_S is the gaps between content of soil microaggregates (>0.05 mm) and content of soil particle (>0.05 mm).

(4) Aggregation degree (A_D)

$$A_D = \frac{A_S}{M_{A>0.05}} \times 100\,\% \tag{3}$$

where, A_S is aggregation status and $M_{A>0.05}$ represents accumulative content of soil microaggregates in diameter smaller than 0.05 mm.

(5) Mean weight diameter of wet aggregate (W_{MWD})

It is the production of mean diameter (mm) of each range of wet aggregate and its weight content (%).

(6) Equivalent pore (E_P)

It was defined as: d=3/h, in equation, d is equivalent pore diameter (mm); h is water absorbing capacity (figuring with centimeter water pole). The equivalent pore proportion was the proportion between equivalent pores with diameter of >30μm and <30μm.

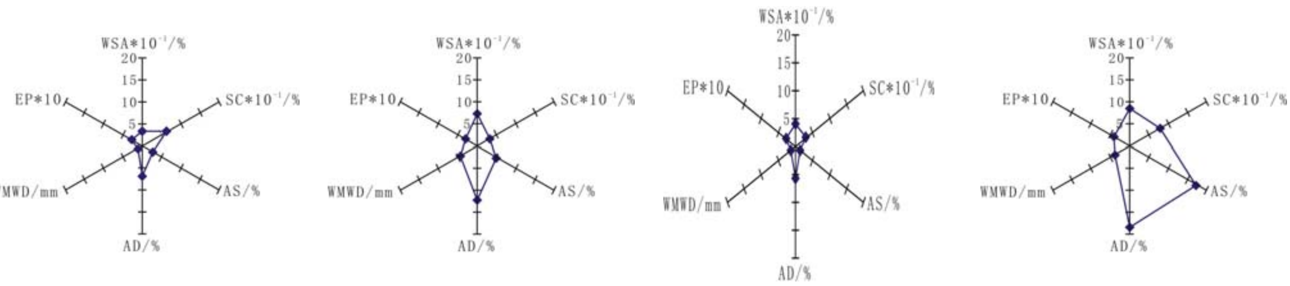
All the assessing indices mentioned above are positive. Usually the higher the value, the better the structural quality of soil is. The radar diagrams of structural quality of soil assessment constructed by six indices mentioned above were shown in Fig. 1, and the area connected by 6 indices could express soil structural quality. The results revealed that all these indices in plantation were lower than those in natural forests. Thus, the structural quality of soil in plantation is obviously poorer than that in natural forest.

Discussion and conclusion

According to our study result, it is concluded that the soil degradation is very serious in typical plantation in upper reaches of Yangtze River, which may induce plantation degradation..

Main causes of degradation of structural quality of soil

Some researchers reported that the different upgrowth regularities for *Alnus cremastogyne* and *Cupressus funebris* induced a succession trend from a mixed forest of the two species in early stage to a pure *C. funebris* forest in the late stage, because the two species had different growth periodicity. *A. cremastogyne* can reach the highest growth rate at the 10th year after planting, while the highest growth rate of *Cupressus funebris* is at age of 18 (Shi *et al*. 1996a, 1996b). However, the radical cause of degradation of the mixed plantation in 10–20 years after planting still needs further explanation. Our results suggest that the degradation of structural quality of soil occurred along with the variation of mixed plantation probably induce and accelerate the plantation degradation. The causes of degradation of structural quality of soil in mixed plantation of *A. cremastogyne* and *C. funebris* can be summarized as: (1) The scientific management is absent in afforestation, particularly in agricultural districts with a big population, thus frequent anthropogenic trampling on soil in woodland had seriously destroyed soil structure; (2) The soil in the plantation is not covered by litter layer, due to the fact that a great proportion of energy sources in countryside come from the litter, as a result, the soil lost supply source of organic matter, and the formation of soil structure and soil stability are consequently affected; (3) Shrubs and herbs are rich under natural forest. In contrast, there are usually no other plants in plantation. Natural formation and restoration of soil structure in a sense rely on biological agent. It is difficult to resume and sustain for the soil structure without biotic community.



Soil in plantation (YT07A) Soil in plantation (YT08A) Soil in plantation (YT09A) Natural forest soil (GG01A)

Fig. 1 Radar diagrams of structural quality of soil assessment from Yanting County and Gongga Mountain, Sichuan Province

Countermeasures of protecting and improving structural quality of soil in woodland

(1) We should enforce long term of closure and reservation system and reduce anthropogenic disturbance and destroy. Thus, soil structure in woodland could form and restore naturally while trees are protected.

(2) Correct and diverse planting model should be applied to ecological rehabilitation according to different climate and soil properties in process of the construction of plantation in upper reaches of Yangtze River. It is important to plant some vegetation in favour of the restoration and protection of structural quality of soil such as nitrogen-fixing plant and grass family.

(3) Some measures such as rebuilding soil litter layer artificially, increasing the treatment with organic fertilizer, adjusting soil nutrient environment (acidity, alkalescence, calcareous properties and so on) and the soil nutrient element balance should be enforced according to the degradation features of soil structure in woodland. As a result, the soil ecological function and structural quality of soil were improved through increasing soil fertility.

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